To study the interface effect in pile supported asymmetrical building using DSSI analysis

by

Pallavi Ravishankar, Neelima Satyam

in

4th International Conference on Civil Engineering and Building Materials (CEBM2014)

Hong Kong

Report No: IIIT/TR/2014/-1

Centre for Earthquake Engineering
International Institute of Information Technology
Hyderabad - 500 032, INDIA
November 2014

To study the interface effect in pile supported asymmetrical building using DSSI analysis

Badry Pallavi R.
Research scholar pallavi.ravishankar@research.iiit.ac.in

Dr. Neelima Satyam D.
Assistant Professor neelima.satyam@iiit.ac.in, Geotechnical Engineering Laboratory; Earthquake Engineering Research Center, International Institute of Information Technology Hyderabad, INDIA

ABSTRACT: In order to get the exact response of the structure under the earthquake loading, it is necessary to include the interaction effect in the analysis. This can be achieved by introducing an interfaces element between two target surfaces. It is a very challenging task to include the interaction effect in the analysis as it is very complex and governed by the many factors including impedance, wave propagation, resonance, damping, nonlinear behaviour of the interface elements, soil nonlinearity etc [10]. In the present study, the 3-story asymmetrical building supported by pile foundation is considered for the analysis. Dynamic analysis is carried out in time domain by applying a Bhuj (2001,0.31g) ground motion and the response of the superstructure is predicted in the form of displacements. The elastic half space is considered as supporting local soil which included the horizontal stratification with four soil layers. The parametric study has been carried out for a different size of interfaces element between soil-pile and soil-soil and the response is compared with the rigid interface condition to understand the influence of the interface on the SSI response. The response with the rigid interface condition is found to less as compared to the interface conditions and the response varies with the size and strength of the interface element.

Keywords: DSSI, Soil pile interaction, Asymmetrical building, Interface effect

1 INTRODUCTION

Dynamic Soil Structure interaction (DSSI) is a very complex phenomenon to implement in real design practice for a structure as it governed by several parameters including attenuation of waves through soil, nonlinear soil behaviour under dynamic loading, interface nonlinearity, soil behaviour, impedance of the soil strata and superstructure inertia [10,13]. In most of the design practices the superstructure is assumed to be founded on the rigid bed rock which dilutes the reality of soil as a supporting media for the foundation, which predicts the incorrect response of the system under dynamic transient loads like Earthquakes. To understand the soil structure interaction and analyze the system nearer to the actual one, many researchers made an attempt to consider soil strata in a foundation system. Considering a soil as a homogenous under the foundation again it violates the reality that soil medium is highly heterogeneous which give rise to the impedance and the attenuation for the dynamic loading [14]. Thus to estimate the structural behaviour against the dynamic loading supported on a deep foundation system with soil heterogeneity is very challenging.

1.1 *Theory and background of SSI*

An elastic half space theory has been introduced to understand phenomenon of soil structure interaction [13]. Ground motions that are not influenced by the presence of structure are referred as free field motions. Structures founded on rock are considered as fixed base structures. When a structure founded on solid rock is subjected to an earthquake, the extremely high stiffness of the rock constrains the rock motion to be very close to the free field motion and can be considered as a free field motions and fixed base structures. Dynamic analysis of SSI can be done either using direct method or Substructure Method. Direct approach is one in which the soil and structure are modeled together in a single step accounting for both inertial and kinematic interaction. Substructure method is one in which the analysis is broken down into several steps that is the principal of superposition is used to isolate the two primary causes of SSI [13]. If the structure is supported on soft soil deposit, the inability of the foundation to confirm to the deformations of the free field motion would cause the motion of the base of the structure to deviate from the free field motion. Also the dynamic response of the structure itself would induce deformation of the supporting soil. This process, in which the response of the soil influences the motion of the structure and the response of the structure influences the motion of the soil, is studied under the interaction effects and termed as the Dynamic Soil Structure Interaction (DSSI), as shown in Fig. 1.

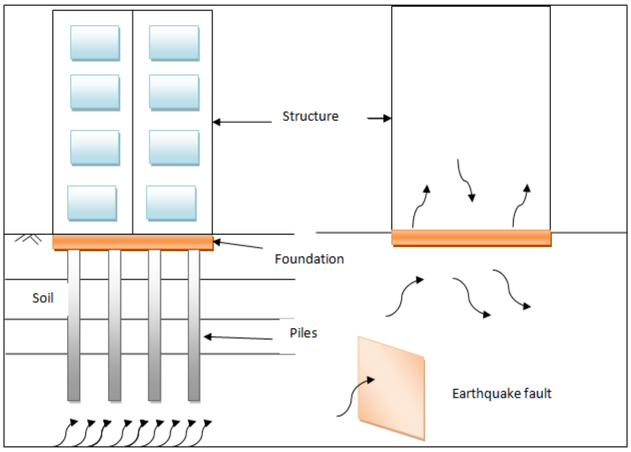

Figure 1. General scenario of consideration of soil structure interaction effect and wave propagation [13].

These effects are more significant for stiff and/ or heavy structures supported on relatively soft soils. For soft and /or light structures founded on stiff soil these effects are generally small. It is also significant for closely spaced structure that may subject to pounding, when the relative displacement is large [10].

1.2 *Focus of the resent study*

In this research paper the effect of interfaces in the soil heterogeneity and pile soil contact is studied. A dynamic analysis has been carried out by developing a finite element model using Plaxis 2D [12] and the superstructure response is studied for different sizes and strength of interface elements.

2 DSSI MODELLING OF BUILDING

2.1 Soil Details

To capture the real time scenario of an analysis the soil heterogeneity is considered including the four horizontal stratified zones including medium dense (S1), dense (S2), medium stiff (C1) and stiff (C2). The details of the each soil layers each type of soil is described in Fig. 2.

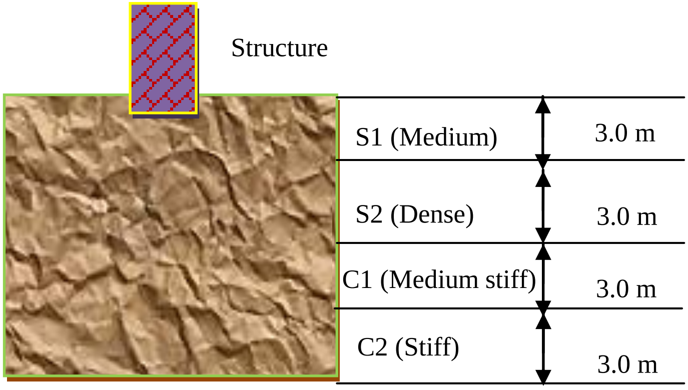

Figure 2. Details of soil layers considered in present study.

The engineering properties of the soils zones are detailed in the Table 1. The 3 Storey pile supported R.C.C. building is considered for analysis is assumed to be founded on such heterogeneous soil condition.

Table 1. Engineering properties of the soil layer considered in the present study.

Parameter	Soil Type			
	S1	S2	C1	C2
Unit Wt. (γ_{sat}) (kN/m^3)	20	21	19	20
Cohesion, C_u, (kN/m^2)	0	0	40	80
Friction angle, ϕ' (^{0})	32	38	0	0
Poisson's Ratio	0.47	0.38	0.4	0.45
E_{ref} (kN/m^2)	6000	12000	4500	9000

2.2 *Structure and foundation details*

A 3 storey structure with pile foundation is considered in the present analysis. The details of the structure model are given in Table 2 as below.

Table 2. Details of the structure model considered in the present study.

Parameter	Descriptions
Asymmetry	Loading
Height	9 m
Asym. Ht.	3 m
Base Dimension	6 x 6 m
Beam and column	0.25 x 0.25 m , 3m Length/Height
Pile configuration	0.25 m dia x 6 m at 3 m c/c
Grade of concrete	M_{30}

2.3 Finite Element Modeling

In present study structural elements like beam and column and pile foundation is modeled with plate element. Plates in the 2D finite element model are composed of plate elements (line elements) with three degrees of freedom per node viz two translational degrees of freedom (ux,uy) and one rotational degrees of freedom (rotation in the x-y and @ plane z). The plate elements are based on Mindlin's plate theory [9]. This theory allows for plate deflections due to shearing as well as bending. In addition, the element can change length when an axial force is applied. Plate elements can become plastic if prescribed maximum bending moment or maximum axial force is reached. Soil is modeled with 15 node plate element.

Interfaces or joint elements need to model adjacent to plates element to allow for a proper modeling of soil-structure interaction. In present study soil pile interaction is achieved by modeling interface element at soil and pile element at both side of the pile. The contact between different soil strata is also model by proper size of interface element. The roughness of the interaction is included by choosing a suitable value for the strength reduction factor which is governed by the friction theory of the different and same type of material [8]. As per the properties of the interface element is defined as expressed in Equation 1 and 2.

$$C_{inter} = R_{inter} * C_{soil} \qquad (1)$$

$$\tan(\varnothing)_{inter} = R_{inter} * \tan(\varnothing)_{soil} \qquad (2)$$

Where C and Ø are the cohesion and angle of friction which is used in the material model of the interface material and R_{inter} is the strength reduction factor of the interface element which can be taken as a size factor with respect to the global element size of the model.

Each interface has assigned to it a virtual thickness which is an imaginary dimension used to define the material properties of the interface. The higher the virtual thickness is the more elastic deformations are generated. In general, interface elements are supposed to generate very little elastic deformations and therefore the virtual thickness should be small. On the other hand, if the virtual thickness is too small, numerical ill-conditioning may occur [8,12]. Thus the proper understanding is required to model the interface element thickness and can be implemented in modeling by virtual thickness factor which calculated as the virtual thickness factor times the global element size (size of the element at the time of mesh generation).

In dynamic soil structure interaction problem the far filed is modeled by the viscous boundary conditions in order to avoid the reflection of the waves during the earthquake. It is always preferred to model far field with viscous boundaries than the standard fixities in order to absorb waves that reach the model boundaries and that would result in spurious reflections otherwise [3,6]. A viscous boundary is aimed to absorb the increments of stresses on the boundaries caused by dynamic loading, which would be reflected inside the soil body.

The structure and foundation system is subjected to the Bhuj ground motion (2001, 0.31g). The dynamic loading is applied at the bottom of the soil domain and the response of the structure at each storey level and pile levels are estimated. The analysis is carried out for the different interface element sizes and the response of the structure is compared with the rigid interface condition between pil soil and soil soil in at the soil strata.

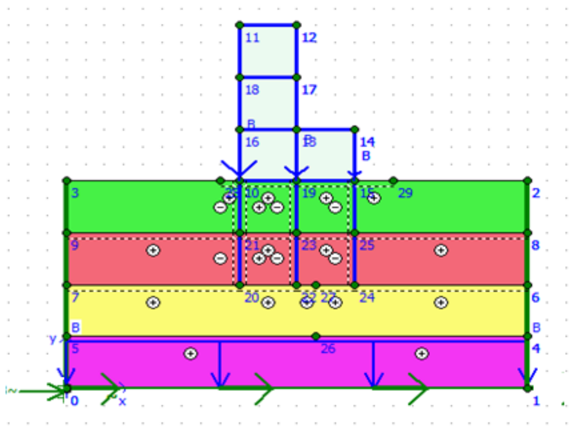

Figure 4. Finite Element model for the interaction analysis.

3 RESULTS AND DISCUSSION

The 3 storey pile supported R.C.C frame is analyzed for the Bhuj ground motions applied at the bottom of the finite soil domain and response of the structure at each storey and at different foundation levels including different size of interface elements. The time domain displacement history for interface element R_{inter} 0.2 for different points shown in Fig. 5 along the height of the model is shown in Fig. 6.

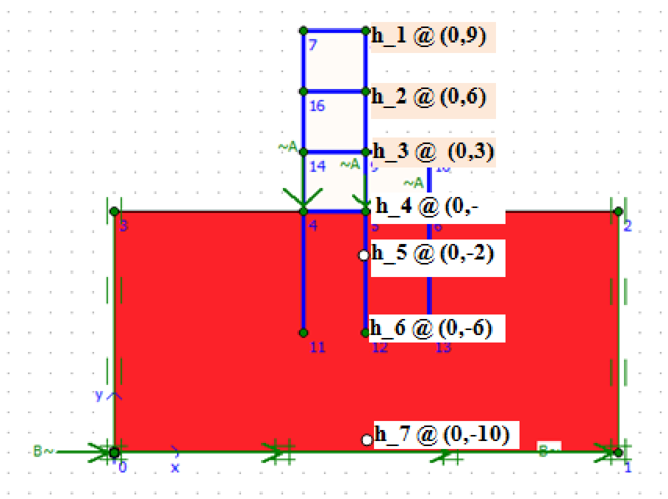

Figure 5. Response locations.

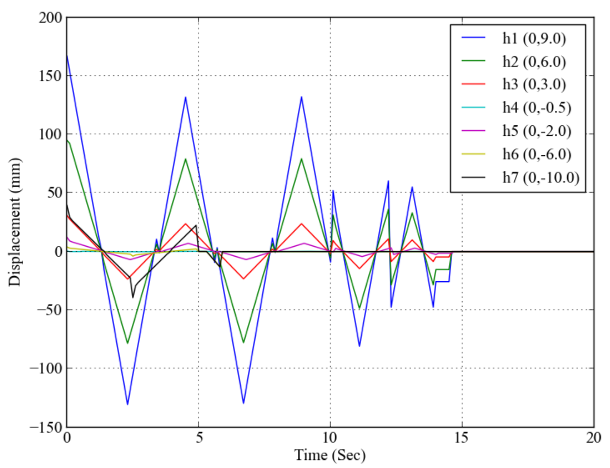

Figure 6. Displacement history at different locations along elevation of the model.

The peak response condition is studied further to understand the effect of n interface element size and area in terms of the strength factor R_{inter} which is the coefficient reflects strength and shape with respect to the maximum global element size. The R_{inter} value varies from 0.2 to 0.8 to study its effect on peak displacement of the superstructure. The response at the top storey is observed at different interface configuration (Fig.7).

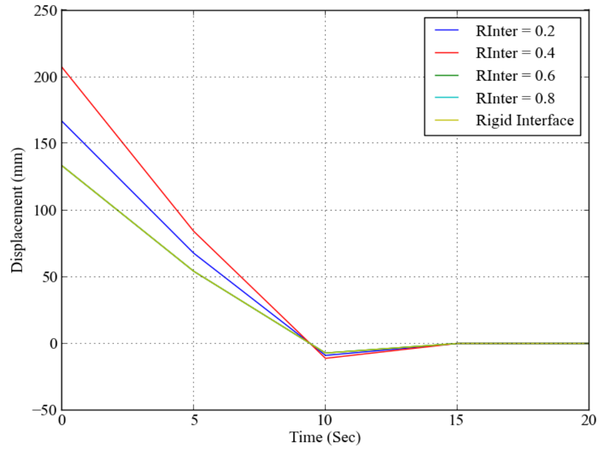

Figure 7. Displacement history at top (h=0, 9.0) for different interface configuration.

4 CONCLUSIONS

The dynamic analysis for pile supported three storey building has been carried out using Geotechnical Finite Element tool, Plaxis 2D [12]. The soil heterogeneity is included to meet the actual scenario considering the four horizontal stratified zones like medium dense (S1), dense (S2), medium stiff (C1) and stiff (C2) for soil structure interaction effect. The response of the system is studied for different interface sizes and strength ranging from 0.2 to 0.8 and the results are compared with the rigid interface conditions. Analyzed for Following are few conclusions drawn from the present study.

- All stories of the superstructure follows the same displacement profile with different peak displacemnt value.The pile cap and centre of the pile also follows the same displacement pattern and attains the full damping condition at in an average 15 sec for all analysis cases.
- Displacement at the bottom of the pile follows very mild curve and attains the full damping condition at very early stage of the i.e in average 5 sec for all cases.
- The displacement of the soil is comparively more than the displacement at the pile bottom but system dessipates in a short time than the above ponts.
- The response of the superstructure and foundations system is found to be varies with the interface reduction factor but the change in the response is less than 20 %.
- As the R_{inter} increases fro 0.1 to 0.5 the system behaves like flexible and gives higher value of the displacements. as compared to the other valuse from 0.6 to 1.0

- As Rinter increses from 0.6 onwards it gives the lesser displacements and the difference between the respnse for the values are negligibly small.
- The study has found that the resopnse of the system is more in case of inteface condition as compare to the rigid contact.

REFERENCES

[1] Ambrosini R.D.(2006) Material Damping vs. Radiation Damping in Soil–Structure Interaction Analysis. Computers and Geotechnics 33:86–92.

[2] Bowles J.E. (1996) Foundation Analysis and Design.McGraw-Hill International Editions,
5th edn, Civil Engineering Series.

[3] Brebbia, C.A., Telles, J.C.F, Wrobel, L.C. (1983). Boundary Element Techniques, Springer-Verlag, NY.

[4] Carr, A.J. 2008, Soil-Structure Interaction, Advanced nonlinear seismic structural analysis notes, Pavia.

[5] Chopra, A.K. & Gutierres, J.A. 1973, Earthquake Analysis of Multistorey Buildings Including Foundation Interaction, ReportNo.EERC73-13, University of California, Berkeley.

[6] Chopra A.K., Gutierres J.A.(1973) Earthquake Analysis of Multi storey Buildings Including Foundation Interaction. ReportNo.EERC73-13, University of California, Berkeley.

[8] Min Kyu Kim, Jong Seh Lee, Moon Kyum Kim (2004) Vertical Vibration Analysis of Soil-pile Interaction Systems Considering the Soil-pile Interface Behavior. KSCE Journal of Civil Engineering 8:221-226.

[9] Kojić, M., and K. J. Bathe (2005). *Inelastic Analysis of Solids and Structures*. New York, NY Springer, ISBN: 9783540227939.

[10] Kramer S.L. (2003) Geotechnical Earthquake Engineering. 1st Edtn. Prentice Hall.

[11] Pallavi Ravishankar, Neelima Satyam (2013). Finite element modeling to study soil structure interaction parameters for tall structures, Proceedings in 18th ICSMGE workshop of TC207 Soil-Structure Interaction and Retaining Walls, Paris, France.

[12] Plaxis 2D user manual (2008), Build 6972, Anniversary edition.

[13] Wolf J. P. (1985) Dynamic soil structure interaction. Prentice-Hall, Englewood Cliffs.

[14] Wei-Cheng Lo, Chao-Lung Yeh, Chang-Tai Tsai (2007) Effect of soil texture on the propagation and attenuation acoustic waves at unsaturated conditions. Journal of Hydrology. DOI: 10.1016/j.jhydrol.2007.02.034